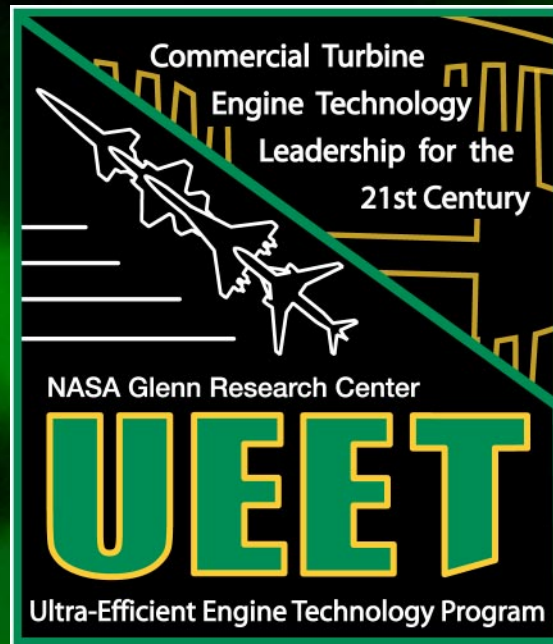




# **Ultra-Efficient Engine Technology Program**



**Fiscal Year 2001  
Performance Report**

## Message from the UEET Program Manager

**W**e in the UEET Program are most pleased to provide this Fiscal Year 2001 Performance Report to interested customers, partners, and stakeholders. The UEET Program is NASA's turbine engine technology program dedicated to continuing the long standing leadership role played by NASA in developing and transitioning the enabling technologies required by U.S. manufacturers. The technologies being developed by the UEET Program will enable the U.S. manufacturers to design future generations of commercial gas turbine engines that will be leaders in the world aerospace marketplace.

President Bush in his **President's Management Agenda** for Fiscal Year 2002 challenged the executive management in all government agencies to consider the following questions:

"Is this program needed?"

"Is it a wise use of the organization's finite resources?"

"Could these resources be used better elsewhere?"

We believe there are very positive answers to these questions when the UEET Program is evaluated. We believe the program exhibited outstanding performance over the course of the past fiscal year from cost, schedule, and technical perspectives. Furthermore we believe the solid plan we have for the out years provides us with a pathway to continued success in addressing the highest priority technology needs required for future gas turbine propulsion system designs which will have revolutionary improvements in performance and reductions in emissions levels.

Successful programs occur not only because of solid, well thought out program and project plans but also because of the commitment and dedication of talented, motivated personnel. The UEET Program is privileged to have a diverse, talented workforce across NASA, industry, and academia who are committed to working together to realize the program vision and goals.

We invite you to read this report and form your own conclusions. We are most interested in your feedback and comments. Please feel free to contact me at (216) 977-7135 or Robert.J.Shaw@grc.nasa.gov with any comments or suggestions you would care to offer. We would also encourage you to follow the progress of the UEET Program by utilizing our program's web site ([www.ueet.nasa.gov](http://www.ueet.nasa.gov)). We will utilize this Internet-based tool as a central part of our programmatic communication strategy.



**Robert J. Shaw**  
NASA UEET Program Manager

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## Executive Summary

The Ultra-Efficient Engine Technology (UEET) Program had a very successful fiscal year 2001. The program accomplished seven of eight level one milestones, which are in the current baseline schedule. Specifically, a significant multi-year effort was completed to develop a turbomachinery disk alloy. This alloy development effort which was started in the High Speed Research (HSR) Program will have a major impact on the U.S. turbine engine community. This disk material is recognized to be THE state-of-the-art and will provide up to a 150-degree F temperature increase for future turbine engine designers.

The ultra low NO<sub>x</sub> combustor research effort focused during the year on transitioning the exceptional low NO<sub>x</sub> levels recorded in laboratory flame tube (TRL3) tests in fiscal year 2000 into more realistic sector configurations for tests over the 2001–2003 time period.

A conceptual design was completed for a new facility, the Dual Spool Turbine Facility (DSTF) which will be located at NASA Glenn Research Center. This facility will play a critical role in future NASA/DoD/industry partnership tests of advanced highly loaded, closely coupled turbine designs. The DSTF is scheduled to become operational in fiscal year 2005.

Also, the UEET Program consummated key partnerships with DoD, EPA, and FAA during the period. These partnerships help establish UEET in a technology leadership role for providing critical, enabling technologies required for future turbine engine designs which must have increased

performance levels while at the same time having reduced levels of emissions.

Our European aviation competitors recognize the importance of advanced aerospace technology and have established a goal of commercial aviation world dominance in the next 20 years. To support accomplishment of this goal, they have initiated a number of close partnership efforts with closely coordinated government, industry, and academic activities. Their gas turbine efforts mirror closely those of the UEET Program. They have openly stated that desire to take the technologies to a level of readiness (TRL6) through engine demonstrations so they can be incorporated in future designs with acceptable risk. Current funding levels for the UEET Program only permit a limited number of technologies to be brought to the TRL6 level; a majority of the technologies will be carried only through the validation phase (TRL3–5).

NASA recently made public its **Blueprint for Aviation—A Technology Vision for Aviation**. This document lays out a vision for how new technologies can be brought to bear on current issues confronting the aviation industry and open up a whole new era in aviation to provide new opportunities in air transportation safety and efficiency, national defense, economic growth, and quality of life. The UEET Program is positioned to play a key role in supporting the realization of the vision described in the **Blueprint for Aviation**. The UEET contributions are also entirely consistent with the recently released interim report of the President's commission on the Future of the Aerospace Industry.

---

TRL = Technology Readiness Level

**As NASA's turbine engine technology program, the vision of the UEET Program is to:**

*Develop and hand off revolutionary turbine engine propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.*



Since the charter of the UEET Program is to address turbine engine technology requirements for a wide variety of commercial applications, the following goals have been utilized to determine the highest payoff technology investments:

- Propulsion technologies to enable increases in system efficiency and, therefore, fuel burn reductions of up to 15% (equivalent reductions in CO<sub>2</sub>).
- Combustor technologies (configuration and materials) which will enable reductions in Landing Take Off (LTO) NO<sub>x</sub> of 70% relative to 1996 ICAO standards.

The technology payoff assessments are made utilizing the results of NASA in house, university, and corporate partner propulsion and airframe systems studies. For the NASA and university studies a series of reference propulsion systems and air vehicles are utilized as shown in figure 1. These reference systems are meant to be representative of the current state-of-the-art for each vehicle class and therefore are the baselines against which technology contributions are assessed. A second set of reference

systems and vehicles also shown in figure 1 are utilized to evaluate technology synergy opportunities for applicability of the UEET technologies to future general aviation, military, and access to space applications. These study results help in defining the broadest applicability of the technologies and therefore the greatest return on the taxpayer's investment.

The seven projects which comprise the UEET Program are shown in figure 2. NASA Glenn

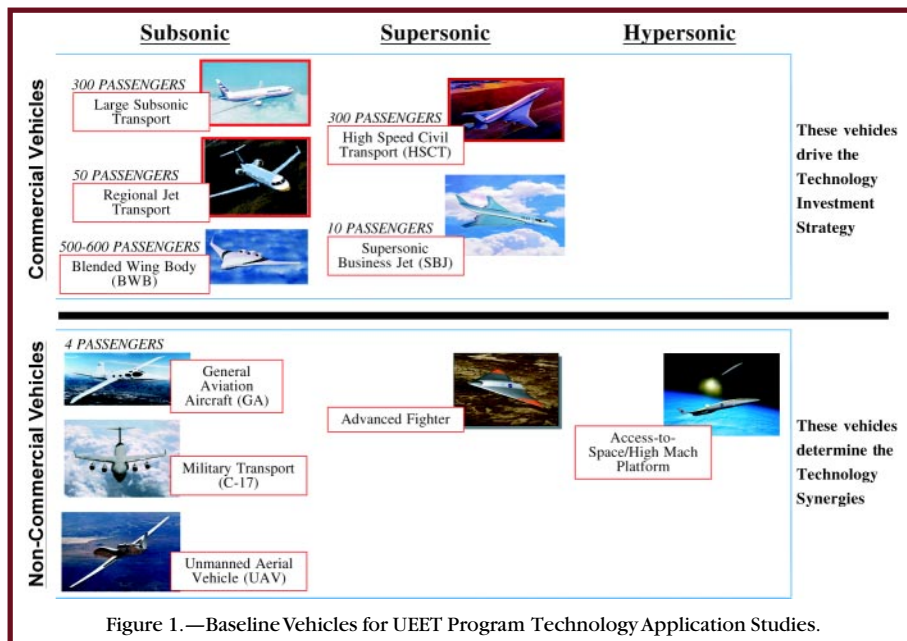


Figure 1.—Baseline Vehicles for UEET Program Technology Application Studies.

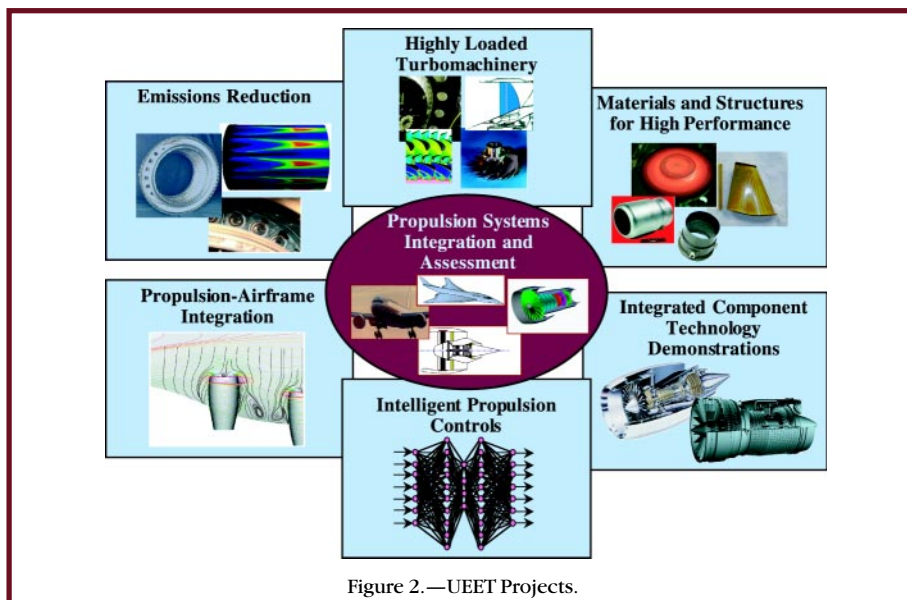


Figure 2.—UEET Projects.

Research Center has been designated to be the lead center for the UEET Program with level one (program) management responsibility being assigned to the UEET Program Office. The seven projects which comprise the UEET Program have active involvement of NASA's Langley, Ames, and Dryden Research Centers as well as the Goddard Space Flight Center. In addition, the UEET Program has seven aerospace companies (Allison/Rolls Royce, Boeing, General Electric Aircraft Engines,

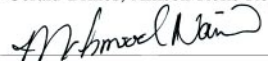
Honeywell, Lockheed Martin, Pratt & Whitney, and Williams International), the Turbine Engine Division of the Air Force Research Labs and one university (Georgia Tech) who have teamed with NASA to execute the program in a partnership fashion. Figure 3 indicates these partners have committed to work with NASA to ensure the success of the program including providing direct in-kind contributions to complement the government resources being provided by NASA.

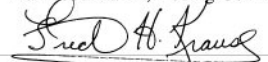
*Develop and hand off revolutionary propulsion turbine engine technologies that will enable future generation vehicles over a wide range of flight speeds.*

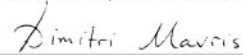
**We support the vision and are committed to the success of  
NASA's Ultra-Efficient Engine Technology (UEET) Program.**

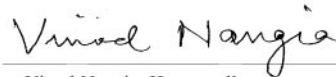
  
Richard Hill, Air Force Research Laboratory

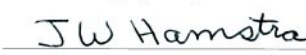
  
Gerald Brines, Allison-Rolls Royce

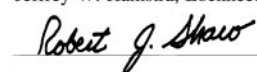
  
Mahmood Naimi, Boeing Commercial Airplane Company

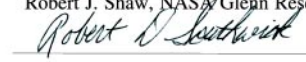
  
Fred Krause, General Electric Aircraft Engines

  
Dimitri Mavris, Georgia Tech

  
Vinod Nangia, Honeywell

  
Jeffrey W. Hamstra, Lockheed-Martin

  
Robert J. Shaw, NASA Glenn Research Center

  
Robert D. Southwick, Pratt & Whitney

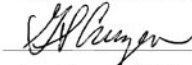
  
Scott Cruzen, Williams International



Figure 3.—UEET—A NASA/Industry/University Partnership.

The most recent technology payoff assessments from the NASA in house propulsion and airframe systems studies are shown in figure 4. The study results indicate that the UEET current portfolio of technologies are projected to meet if not exceed the program goals for both fuel burn reduction and LTO NO<sub>x</sub> reduction. However the amount of test data acquired to date is limited especially for the technologies which contribute to reduced fuel burn, and thus the uncertainty in the current predictions

is large. As the UEET Program acquires critical data through experimental and analytical efforts planned for the outyears of the program, the assessments will be updated and the uncertainty will be considerably reduced. The UEET Program office is working with Georgia Tech to institute a disciplined approach to metrics tracking including employing a probabilistic approach to quantifying the uncertainty in the technology payoff projections.

October 2001		
Goal	Status	Remarks
15% fuel burn reduction for large subsonic	27% projected for 300 PAX	- Systems studies projections of combined impacts of UEET technologies.
8% fuel burn reduction for small subsonic, small / large supersonic	19% for 50 PAX 24% for 300 PAX HSCT 22% for 10 PAX SSBJ	- Study assumptions being reviewed for consistency with project goals.  - Limited test data.
70% NO <sub>x</sub> reduction (below ICAO 96) for subsonic (large regional) combustors over the LTO cycle	Initial flametube tests at NASA GRC show reductions from 73 to 83% for lean combustion concepts (TRL = 3)	Fundamental low-emission combustion concept tests over the simulated landing and take-off (LTO) cycles.

Figure 4.—Program Status.

## Performance Summary

### Technical

Figure 5 depicts the current baseline level one schedule for the UEET Program. Eight level one program milestones were scheduled for completion during fiscal year 2001. Seven of these milestones were successfully completed during the year. The eighth milestone—"2200 deg CMC liner demo"—could not be completed due to a flood occurring in the contractor's test facility and will be completed in the first six months of fiscal year 2002. Over the first two years of the UEET Program, twelve of thirteen scheduled level one milestones have been successfully completed.

For the UEET Program, the phrase "successfully completed" means that at least the minimum success criteria were reached for the milestone. The target objective and the minimum success criteria for all UEET Program level one milestones over the life of

the program have been developed and are available in the program plan.

Appendix A contains more detailed descriptions of the technical accomplishments for each of the seven level one milestones completed in fiscal year 2001.

### Schedule

Relative to the current baseline level one schedule for the UEET Program, eight level one program milestones were scheduled for completion during fiscal year 2001. Six of the seven milestones successfully completed during the previous year were all accomplished within 30 days of the baseline schedule dates while the seventh was completed within 60 days of the scheduled date. The one milestone which was not completed is scheduled for completion within the first six months of fiscal year 2002.

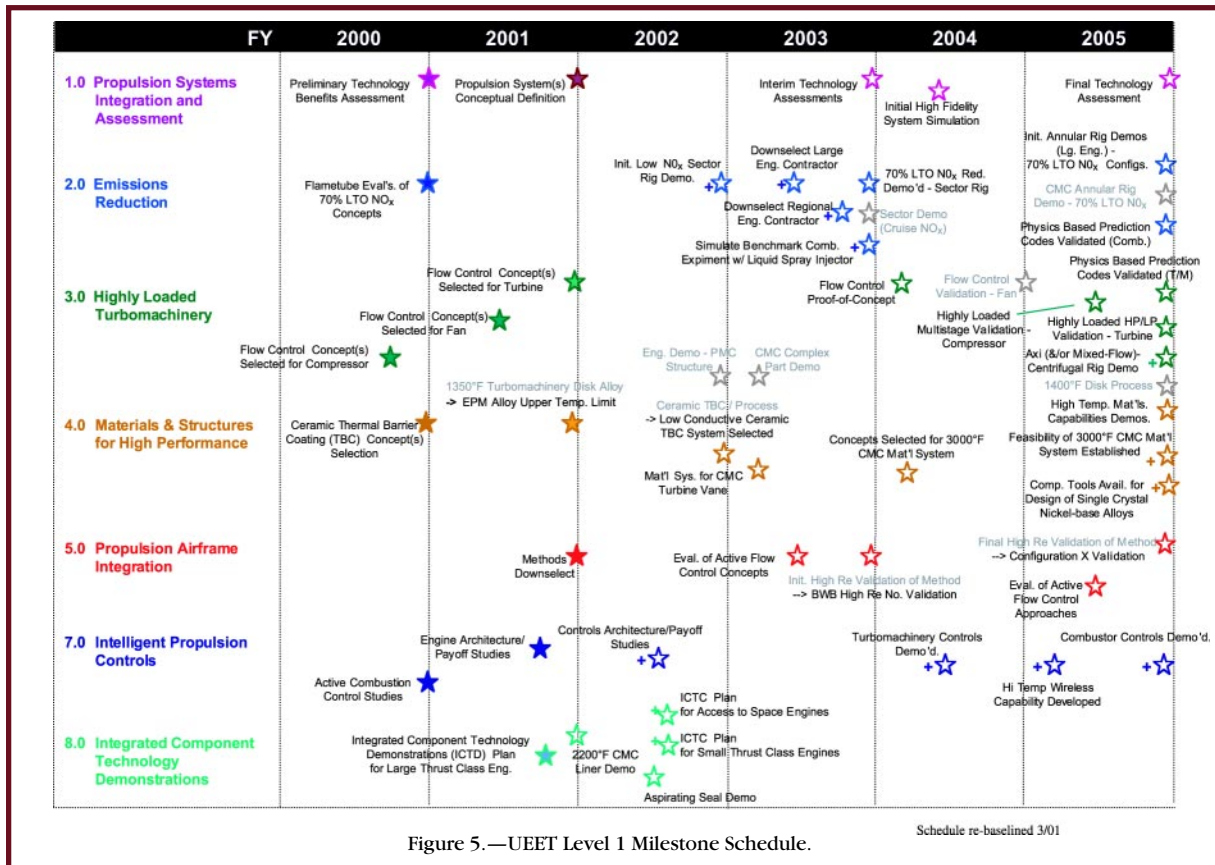


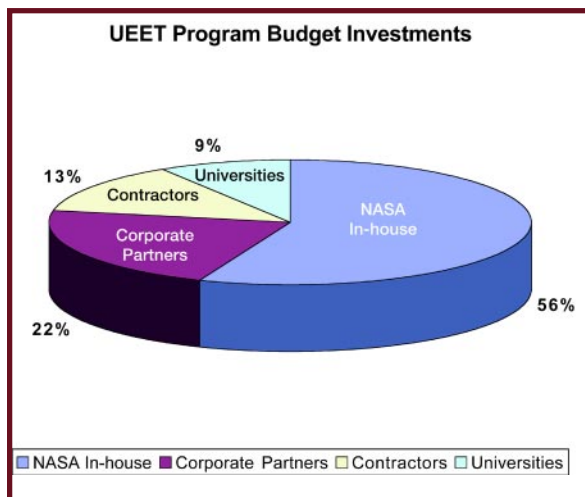
Figure 5.—UEET Level 1 Milestone Schedule.

## Resources

The overall life cycle budget (Gross R & D) for the UEET Program is as follows:

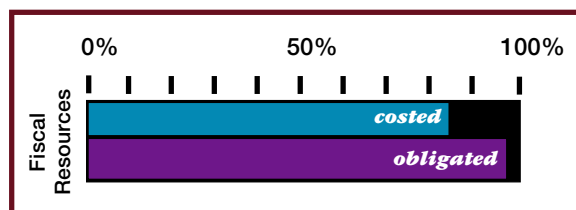
Fiscal Year/\$M						
00	01	02	03	04	05	06
70	48	50	50	50	50	50

The fiscal year 2001 budget authorized by Congress was invested as follows:



Included in the NASA in-house investments was \$2M for the design of a dual spool, counter rotating turbine test facility which will be constructed utilizing UEET Program resources and will be located at NASA Glenn.

Timely, proper utilization of resources is critical to the success of any program, and in fiscal year 2001, the UEET Program:



obligated 98%      costed 85%

of the fiscal resources for which the program office was responsible.

In fiscal year 2001, the UEET Program was allocated 207 civil servant work years at the NASA centers involved in the program. The program utilized over 190 work years to execute the program during the fiscal year.

## External Reviews

In fiscal year 2001, a detailed Independent Annual Review (IAR) of the UEET Program was conducted by a panel of independent experts. The IAR process is the method by which Agency Executive management is apprised on a yearly basis of the status of the major programs being conducted. The panel was co-chaired by Mr. Kerry Christian of the Independent Program Assessment Office at NASA Langley and Mr. George Hopson, Space Shuttle main engine manager at NASA Marshall. Panel members included personnel from NASA Ames, NASA Langley, NASA Johnson, and the Air Force Wright Laboratories. The IAR review was held at NASA Glenn on April 9-12, 2001.

On June 12, 2001 the IAR panel briefed the Agency's Program Management Council (PMC) chaired by Mr. Daniel Mulville, then the Agency's Acting Deputy Administrator. The following comments were included in the executive summary/conclusions portion of the briefing:

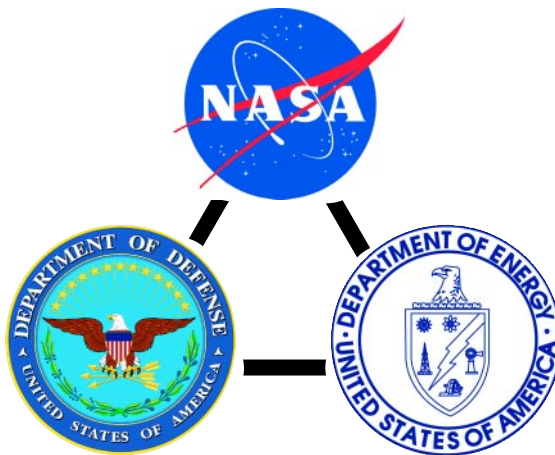
- UEET has made significant progress since the 1999 Non Advocate Review:
  - Satisfied each of the NAR team's recommendations.
  - Excellent tailoring of "7120.5A" (NASA's program/project management handbook) to a focused research and technology program.
  - Good traceability of project technologies to program goals.
  - 5 of 6 level one milestones completed on schedule (Fiscal Year 2000).
  - Good collaboration with DoD, Industry, and NASA.
- Program remains relevant to Agency strategic plan, Industry, and DoD

## External Partnerships

The UEET Program has proactively sought meaningful partnerships with other NASA and federal government programs as well as (where appropriate) international programs so as to achieve more rapid, cost effective technology development and transfer. During fiscal year 2001, the following highlights occurred:

### **Department of Defense/Department of Energy**

The UEET Program is a full partner in the ongoing efforts between NASA, DoD, and DoE to determine technology synergy and collaboration opportunities within existing programs. Specifically in fiscal year 2001 collaborative efforts between UEET, the Air Force and DoE were identified in the area of high temperature engine materials (i.e. ceramic matrix composites, turbomachinery disk, and turbine airfoil material systems). Specific working relationships were agreed to and documented in formal interagency agreements. Also NASA Glenn personnel involved in the UEET Program collaborated with personnel from the Air Force's Wright Laboratories to conduct an emissions characterization test of an advanced military combustor concept.



### **Environmental Protection Agency**

UEET in partnership with the EPA's Office of Atmospheric Programs completed a health impact study to assess the projected impact of a possible future fleet of supersonic commercial aircraft.



### **Federal Aviation Administration**

UEET negotiated and signed an interagency agreement with FAA's Office of Environment and Energy to continue partnership efforts relative to commercial engine emissions characterization and understanding.



### **QinetiQ — United Kingdom**

UEET conducted two partnership tests with QinetiQ to measure the emissions characteristics of an isolated combustor and a full engine system including the same combustor configuration. The data sets acquired will be used to validate the emissions predictive tools being developed by the UEET Program.



## Education and Outreach

All NASA Office of Aerospace Technology (Code R) programs are required to have education/outreach plans. The objective of NASA's education/outreach efforts is to inform the general public about NASA programs and provide specially developed education material for children in grades K through 12 so as to encourage more young people to pursue careers in science and engineering. The UEET Program has

developed an aggressive education/outreach effort specifically focused on commercial aviation and gas turbine engines. The education portion of the plan has been planned and is being implemented in partnership with NASA Glenn's Office of Educational Programs. Selected highlights are displayed below.

**Ultra-Efficient Engine Technology (UEET)**  
NASA Glenn Research Center at Lewis Field

Technology for the most critical propulsion issues that impact local airport air quality and global climate change: reducing nitrogen oxides and improving performance.

**Ultra-Efficient Engine Technology Program Vision**

To develop and hand off *revolutionary* turbine engine propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.

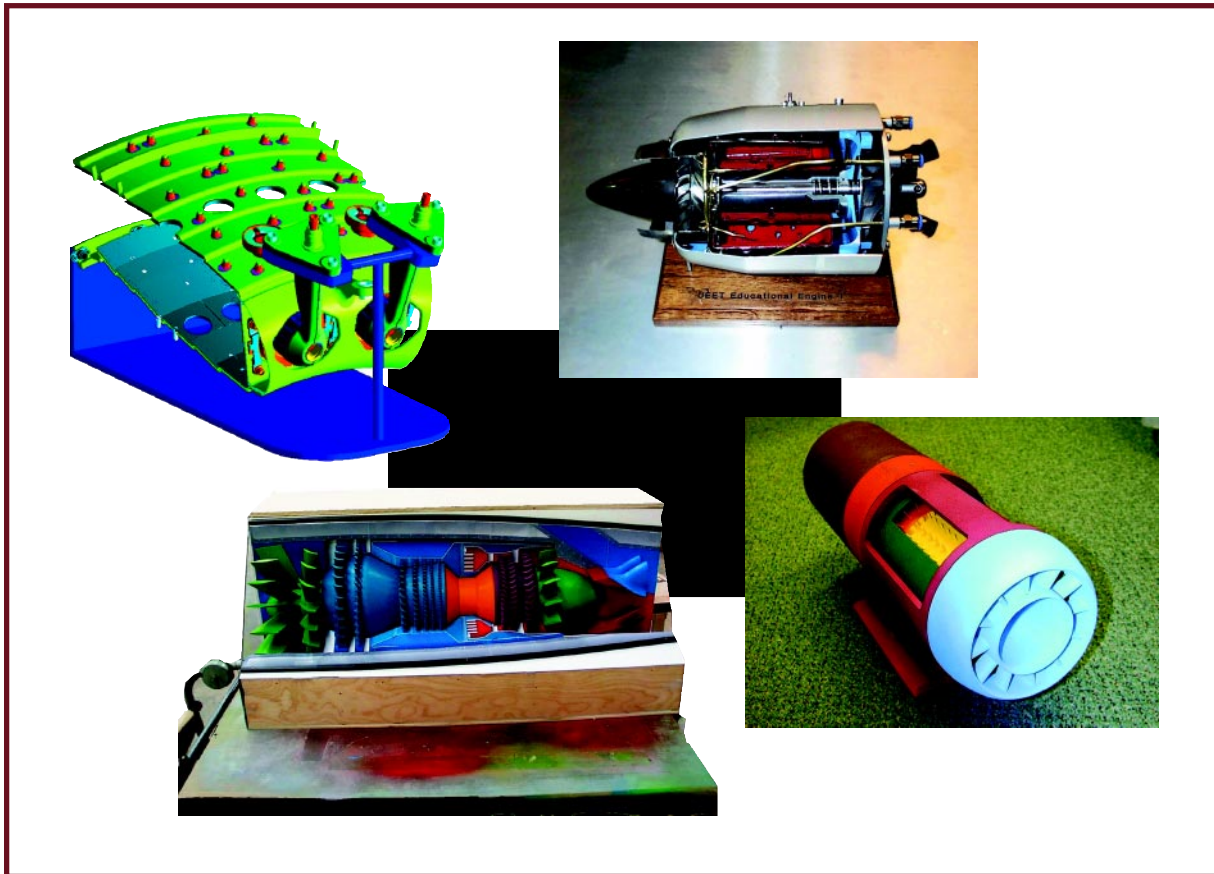
*In fiscal year 2001, the UEET Program web site became operational. This web site will educate the general public about the program as well as provide updated program accomplishments. The web site will continue to evolve and will be the centerpiece of UEET's overall communication strategy.*



*The UEET web site also includes a kid's site which provides a wealth of information including a number of games for children in grades K-12.*

In addition, the UEET Program managed the construction of several gas turbine engine models during the fiscal year. These models are being used to educate the general public about the principles

of gas turbine engine propulsion and the positive impacts of technologies being developed by the UEET Program.

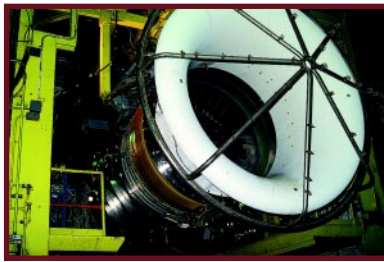


## Technology Transfer

The ultimate measure of success of any NASA Aerospace Technology research program is the documented transfer of technologies to the industrial community which uses them in the design of advanced aerospace systems. The UEET Program is sponsoring the completion of selected high payoff technologies which were originated in the High Speed Research (HSR) and Advanced Subsonic Technology (AST) Programs. In fiscal year 2001 some significant technology transfer/new product introductions occurred:

Pratt & Whitney announced a new low emissions combustor at the 2001 Paris Air Show which reduces Landing/Take Off  $\text{NO}_x$  over 40% below current ICAO regulations.

The technology foundation for this combustor design came from the AST Program. The knowledge gained from the AST Program serves as the foundation for the 70% LTO  $\text{NO}_x$  being conducted in UEET.



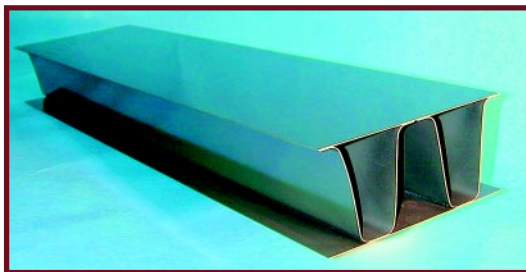
NASA completed a multi-year partnership effort with General Electric and Pratt & Whitney to develop a turbomachinery disk alloy that will truly revolutionize the state-of-the-art for future commercial and mili-

tary engines. The effort was started as part of the HSR Program. The new disk alloy can withstand temperatures in excess of 1300 degrees F



which is some 150 degrees hotter than the current state-of-the-art. Currently, numerous commercial and military engine demonstration programs utilizing the disk material are occurring.

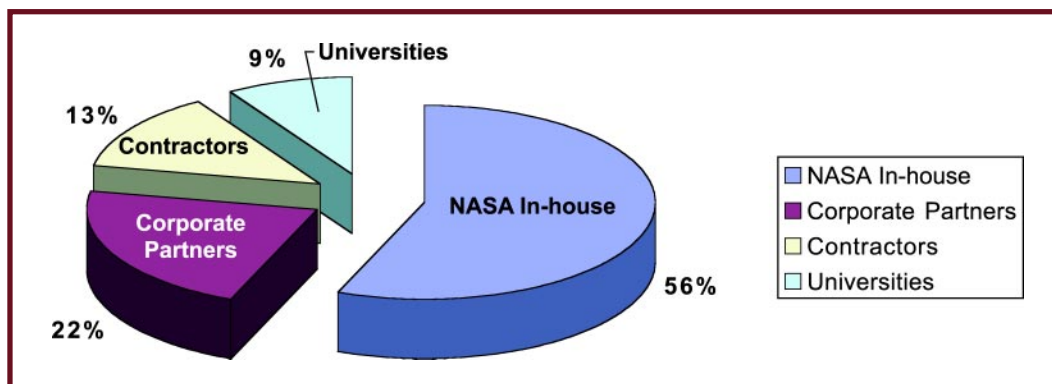
NASA transitioned a materials processing technology initially developed in the HSR Program to NASA and DoD access-to-space programs. The technology enables Titanium Aluminide to be formed into large sheet structures while retaining attractive strength characteristics. The technology is an attractive option for fabrication of a variety of nonrotating structures for air breathing propulsion applications. In fiscal year 2001, this personnel who accomplished this effort received several awards



including the prestigious IR&D 100 award, one of four received by NASA Glenn personnel.

## Resource Investment Details

In fiscal year 2001, the UEET Program budget was invested as follows:



The more detailed list of participants is as follows:

### NASA In-house

- Ames Research Center (CA)
- Dryden Flight Research Center (CA)
- Glenn Research Center (OH)
- Goddard Space Flight Center (MD)
- Langley Research Center (VA)
- NASA Headquarters (DC)

### Corporate Partners

- Allison/Rolls Royce (IN)
- Boeing (CA)
- General Electric Aircraft Engines (OH)
- Georgia Tech Research Corp. (GA)
- Honeywell (AZ)
- Lockheed Martin (CA)
- Pratt & Whitney (CT)
- Williams International (MD)

### Other Government Agencies

- U.S. Air Force Systems Command (TN)
- U.S. Energy Department (IL)
- U.S. Environmental Protection Agency (DC)

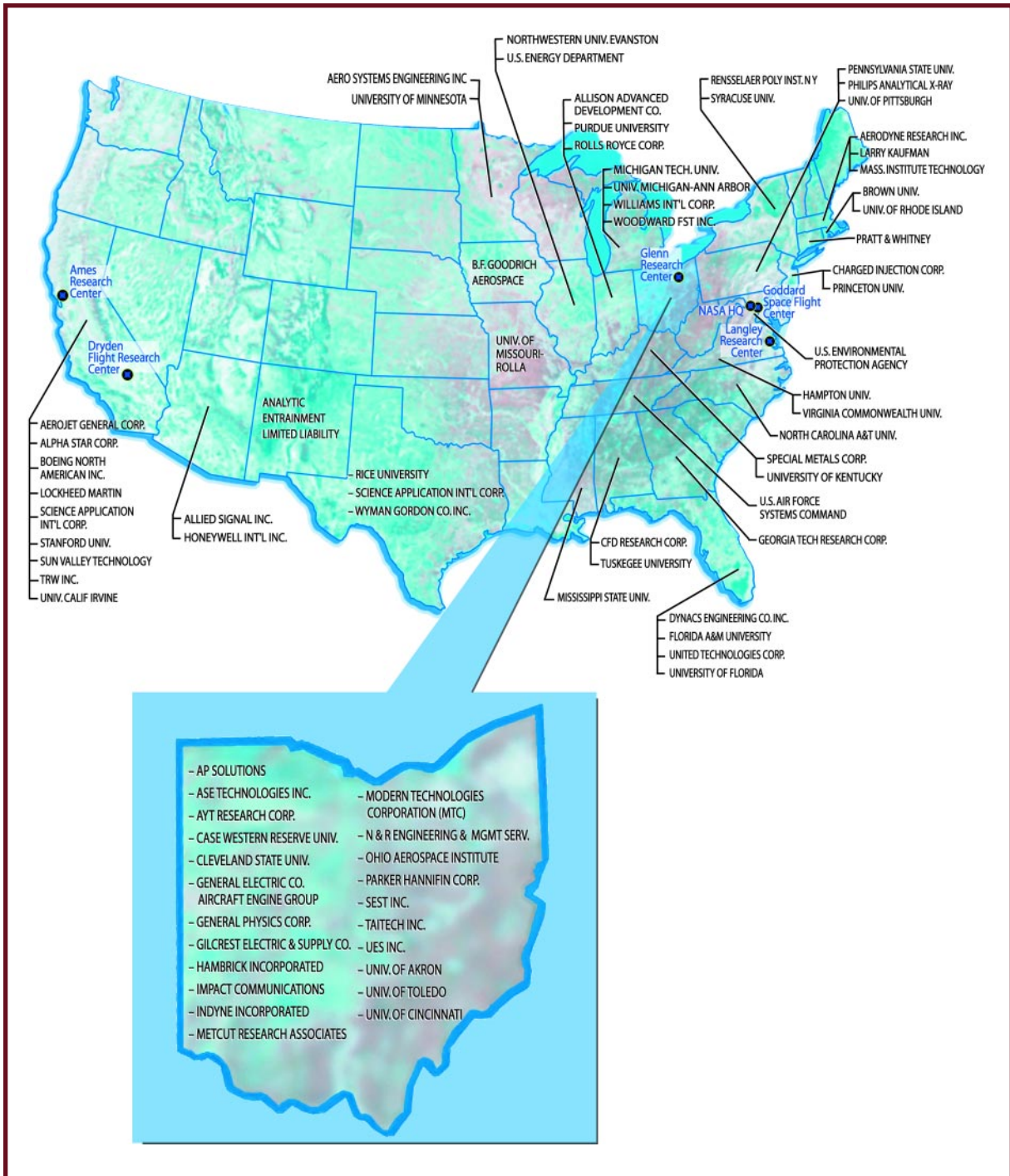
### Contractors

- Aero Systems Engineering Inc. (MN)
- Aerodyne (MA)
- Aerojet General Corp. (CA)
- Allied Signal (AZ)
- Alpha Star Corp. (CA)
- Analytic Entrainment Limited Liability (NM)
- AP Solutions (OH)
- ASE Technologies Inc. (OH)
- AYT (OH)
- B.F. Goodrich (IA)
- CFD Research Corp. (AL)
- Charged Injection Corp. (MD)
- Dynacs Engineering Company Inc. (FL)
- General Physics Corp. (OH)
- Gilcrest Electric and Supply Co. (OH)
- Hambrick Inc. (OH)
- Impact Communications (OH)
- Indyne Inc. (OH)
- Larry Kaufman (MA)
- Metcut Research Associates (OH)
- Modern Technologies Corp.-MTC (OH)
- N&R Engineering (OH)
- Parker Hannifan (OH)
- Philips Analytical X-Ray (PA)
- Science Application International Corp. (CA)
- SEST (OH)
- Special Metals Corp. (KY)
- Sun Valley Tech. (CA)
- Taitech (OH)
- TRW Inc. (CA)
- UES Inc. (OH)
- Woodward FST Inc. (MI)
- Wyman Gordon Company Inc. (TX)

### Academic Institutions

- Brown University (RI)
- Case Western Reserve University (OH)
- Cleveland State University (OH)
- Florida A&M University (FL)
- Hampton University (VA)
- Massachusetts Institute of Technology (MA)
- Michigan Tech. University (MI)
- Mississippi State University (MS)
- North Carolina A&T University (NC)
- Northwestern University-Evanston (IL)
- Ohio Aerospace Institute (OH)
- Penn State University (PA)
- Princeton University (MD)
- Purdue University (IN)
- Rensselaer Poly Institute (NY)
- Rice University (TX)
- Stanford University (CA)
- Syracuse University (NY)
- Tuskegee University (AL)
- University of Akron (OH)
- University of Calif-Irvine (CA)
- University of Cincinnati (OH)
- University of Florida (FL)
- University of Kentucky (KY)
- University of Michigan-Ann Arbor (MI)
- University of Minnesota (MN)
- University of Missouri-Rolla (MO)
- University of Pittsburgh (PA)
- University of Rhode Island (RI)
- University of Toledo (OH)
- Virginia Commonwealth University (VA)

## Resource Investment Participants





***Appendices***  
***Appendix A:***  
***FY2001***  
***Level One Milestone***  
***Technical Highlights***



## Upper Temperature Limit Established for EPM (Enabling Propulsion Materials) Disk Alloy

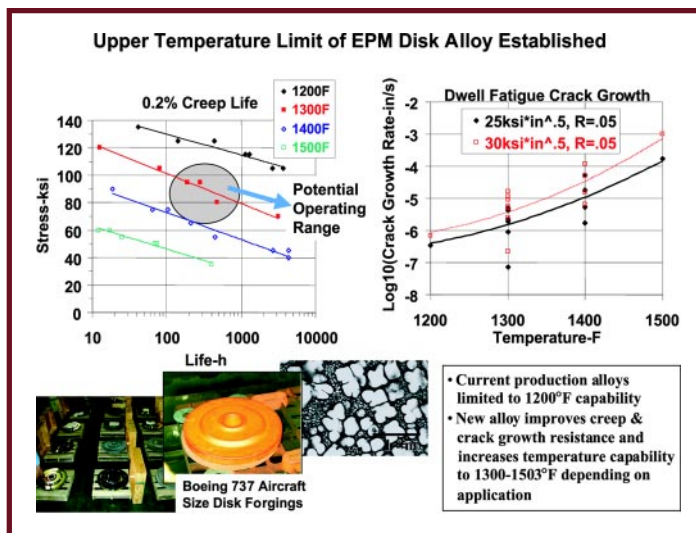
### Point of Contact:

**Robert Draper**  
NASA Glenn  
Research Center  
(714-05)

### Technical Leads:

**Tim Gabb,**  
**Jack Telesman**  
NASA Glenn  
Research Center

**Actual Date of  
Accomplishment:**  
**September 5, 2001**



**Project:** Materials & Structures for High Performance, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Reduced Emissions

**Relevant Milestone:** Establish upper temperature limit of turbomachinery disk alloy as a function of stress.

**Milestone Objective:** Verify project properties of HSR-EPM disk alloy in the temperature range of 1300–1500°F by testing and characterization of large forgings (of 737 engine size) delivered at the end of the HSR Program.

**Milestone Minimum Success Criteria:** Generate property database in the temperature range of 1300–1500°F

**Impact of Technology:** The turbomachinery disk material effort started in the HSR Program and completed in the UEET Program has had a major impact on the U.S. turbine engine manufacturers. This disk material is recognized to be THE state-of-the-art for both commercial and military engines of the future. Numerous engine demonstrators funded by DoD (e.g. IHPTET) and commercial engine applications funded totally by corporate funds are currently occurring.

**Shown:** This EPM disk alloy was developed for supersonic applications and previously exhibited excellent properties in small scale forgings. Shown

are selected results of demonstration of key property improvements for the disk alloy scaled up to commercial (737) engine size disks and tested under the UEET Program.

**Accomplishment/Relation to Milestone and ETO:** Extensive mechanical tests as well as microstructural and fractographic evaluations were completed, and demonstrate that the upper temperature limit for this alloy can be as high as 1350°F, compared to ~1200°F for current production alloys. Quantitative property-temperature relationships were derived to enable technology benefit studies.

**Validation of Milestone Completion:** This milestone was accomplished in partnership with members of the turbine engine community. The 737 size forgings were manufactured by a supplier (Wyman Gordon) and provided to the NASA/industry team. The test data was acquired in NASA test facilities which have been validated by industry for providing FAA certification level of data accuracy. The results will be documented in appropriate publications in fiscal year 2002.

**Next Steps:** The efforts captured by this milestone will be documented in appropriate publications in fiscal year 2002. This will complete NASA's immediate efforts to develop and transition to industry a revolutionary turbomachinery disk material. Efforts in the UEET Program will now focus on the development and validation of computational materials codes which will allow for the future development of designer disk materials tailored to specific turbine engine applications.

## Engine Architecture / Payoff Studies

### Point of Contact:

**Dan Sokolowski**

NASA Glenn  
Research Center  
(714-07)

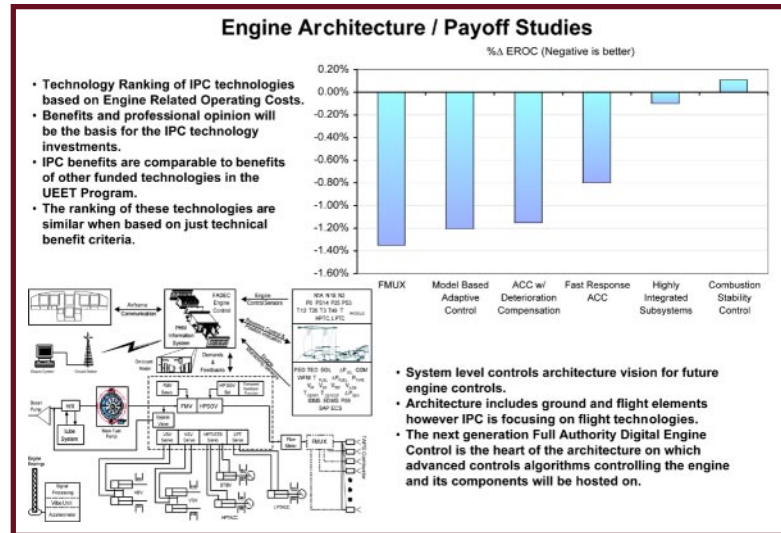
### Technical Lead:

**Gary Hunter**

NASA Glenn  
Research Center

### Actual Date of Accomplishment:

**August 2001**



**Project:** Intelligent Propulsion Controls, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Reduced Emissions (prime), Revolutionize Aviation/Reduced Noise (secondary)

**Relevant Milestone:** Engine Architecture/ Payoff Studies: Complete benefits studies of intelligent propulsion controls for large thrust class engines (>20,000 pounds of thrust). (PCA/Program Plan Milestone No. 5, July 2001)

**Milestone Objective:** Complete benefits studies of intelligent propulsion controls in conjunction with candidate architectures for future engines based on analysis.

**Milestone Minimum Success Criteria:** Complete benefits studies of intelligent propulsion controls in conjunction with candidate architectures for future engines based on limited analysis and expert opinion.

**Impact of Technology:** The engine architecture/ payoff studies will help identify the most promising, highest payoff technologies to pursue in the IPC project which is still under formulation.

**Shown:** The accompanying graphic shows a ranking of IPC technologies based on an Engine Related Operating Cost assessment. This assessment was

done by General Electric Aircraft Engines under contract to NASA. (A similar study was conducted by Pratt & Whitney.) Also a preliminary controls architecture that includes high payoff IPC technologies is provided.

### Accomplishment/Relation to Milestone and

**ETO:** Intelligent Propulsion Controls technology benefits were assessed for large thrust (>20,000 lbs) engine applications by two manufacturers based on existing data and professional opinion and a preliminary IPC architecture was developed. The Minimum Success Criteria for this milestone were met since both system studies benefits analyses and expert opinion of the payoffs had to be employed.

**Validation of Milestone Completion:** The results of the two studies will be documented in NASA contractor reports which will be published in fiscal year 2002. The study results were reviewed by NASA technology experts as part of the report review process.

**Next Steps:** The results of these studies will serve as a key input into updating the baseline project plan which will be reviewed by an independent team of experts as part of the project readiness review (PRR) process currently being conducted. The PRR should be completed by January 2002.

## Advanced Design Method Selected for Propulsion Airframe Integration (PAI) Studies

### Point of Contact:

**Jim Pittman**

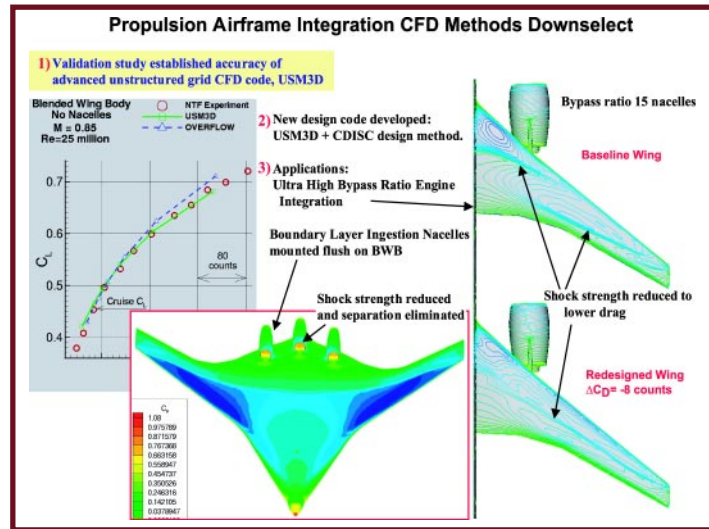
NASA Langley  
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(714-05)

### Technical Lead:

**Dick Campbell**

NASA Langley  
Research Center

**Actual Date of  
Accomplishment:**  
September 2001



**Project:** Propulsion Airframe Integration, Ultra-Efficient Engine Technology Program

**Enterprise Objective Supported:** Revolutionize Aviation/Reduced Emissions

**Relevant Milestone:** PAI CFD Methods Downselect. (UEET Level 1 Program Milestone No. 4, September 2001)

**Milestone Objective:** Select advanced unstructured grid CFD analysis/design method for wind tunnel validation studies of propulsion airframe integration concepts.

**Milestone Minimum Success Criteria:** Continue with industry standard structured grid CFD analysis/design method for wind tunnel validation studies of PAI concepts.

**Impact of Technology:** Accurate, validated aerodynamic design methods are critical to integrating revolutionary propulsion technologies on to advanced aircraft while minimizing aircraft drag and thereby reducing CO<sub>2</sub> emissions. Modern, high-fidelity design tools are based on computer codes that solve the Navier-Stokes equations coupled with design methods that modify the aircraft shape to minimize drag. CFD code grid generation time for complex configurations can take months for a CFD expert using industry standard structured grid technology. Advanced unstructured grid technology

previously has been shown to generate CFD grids significantly faster than structured grid technology for complex configurations thereby reducing the time required to develop revolutionary PAI concepts.

**Shown:** A typical result from validation studies to establish the accuracy of the advanced unstructured grid Navier Stokes CFD code, USM3D. The result shown in the upper left is a drag polar at cruise Mach number 0.85 for a Blended Wing Body configuration without nacelles. Also shown on the drag polar are results from a NASA-developed industry standard structured grid code, overflow, and the experimental data from the Langley National Transonic Facility (NTF). The validation study includes extensive pressure data and a similar study for a conventional jet transport (not shown). This study verified the accuracy of USM3D, which was then coupled with the CDISC automated design method. The new USM3D/CDISC design code was next applied to advanced PAI concepts. The integration of ultra high bypass ratio engines was examined on a conventional jet transport. Nacelles for bypass ratio 15 engines were integrated with a conventional jet and a typical result is shown on the right side of the figure. The USM3D/CDISC design method was used to modify the wing geometry to reduce shock strength yielding a drag reduction of 8 drag counts at cruise Mach number 0.85. The USM3D/CDISC method was also applied to the integration of boundary layer ingestion nacelles, which are mounted flush on top of the wing, with the Blended Wing Body. The strength of nacelle shocks was reduced and boundary layer separation between the nacelles was eliminated.

## Advanced Design Method Selected for Propulsion Airframe Integration (PAI) Studies-Cont'd

### **Accomplishment/Relation to Milestone and**

**ETO:** A rigorous validation and development activity has been performed to develop a new, accurate and robust aerodynamic design method for advanced propulsion airframe integration concepts. Current engine technology in the fleet is bypass ratio 9 engines on the Boeing 777. Ultra high bypass ratio engines are expected in the future to reduce aircraft CO<sub>2</sub> emissions 15% or greater. The new USM3D/CDISC design tool demonstrated the ability to efficiently integrate significantly larger engines with bypass ratio 15 on a conventional jet. A revolutionary configuration, the BWB, was also investigated. The BWB, but with podded nacelles, has 20% CO<sub>2</sub> emissions reduction compared to the same technology conventional jet. An additional 10% CO<sub>2</sub>

emissions reduction is predicted by replacing podded nacelles with flush-mounted boundary layer ingestion nacelles.

**Validation of Milestone Completion:** Preliminary documentation was delivered at the UEET Forum in September 2001. More extensive documentation will be completed in fiscal year 2002.

**Next Steps:** An advanced PAI concept, boundary layer ingestion nacelles integrated to the BWB, will be fabricated as a wind tunnel model and tested in the Langley National Transonic Wind Tunnel Facility in fiscal year 2003 to validate the design study at Mach 0.85 and near-flight Reynolds number. This test will mature the design code technology to a readiness level of 5.

## Propulsion System(s) Conceptual Definition

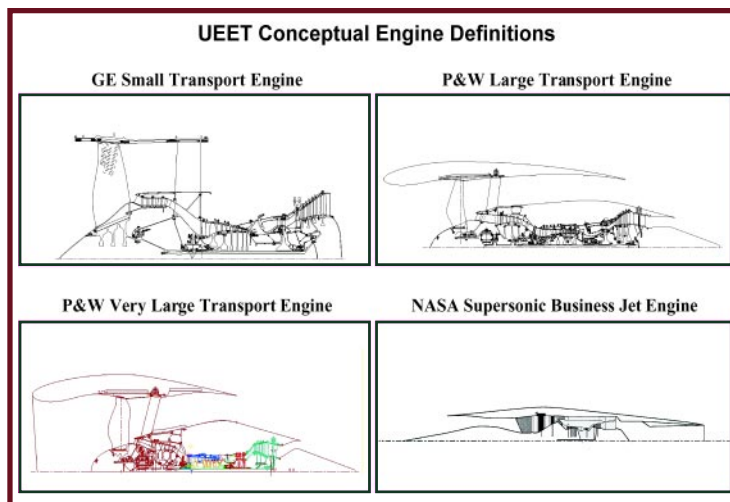
**Point of Contact:**  
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(714-01)

**Technical Lead:**  
**Rich DeLoof**

NASA Glenn  
Research Center

**Actual Date of  
Accomplishment:**  
**September 30, 2001**



**Project:** Propulsion Systems Integration and Assessment, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Emissions Reduction (prime), Revolutionize Aviation/Noise Reduction (secondary)

**Relevant Milestone:** Propulsion System(s) Conceptual Definition: Based on supporting trade studies, conceptually design optimum propulsion systems. PCA milestone and Program Level 1 Milestone.

**Milestone Objective:** Conceptually design optimum propulsion systems for four aircraft classes based on supporting trade studies, including definition of major component design parameters, engine cycle, and engine flow path/weight.

**Milestone Minimum Success Criteria:** Conceptually design optimum propulsion systems for two aircraft classes based on supporting trade studies, including definition of major component design parameters, engine cycle, and engine flow path/weight.

**Impact of Technology:** These studies conducted by NASA and industry personnel identify promising approaches for meeting both goals of the UEET Program. These results also identify the projected pay-offs of each of the technologies currently in the UEET portfolio, technologies proposed by each company and thus are a key input into potential adjustments to the programmatic investment strategy.

**Shown:** Engine flowpaths for four conceptual designs. The designs are for the following four vehicle classes: Large Subsonic Transport, Supersonic Business Jet, Small Subsonic Transport and a very large Blended Wing Body Transport.

**Accomplishment/Relation to Milestone and ETO:** Four conceptual system designs were completed by the GE, P&W and NASA study teams. These advanced cycles were designed for a 2010 Technology Availability Date (TAD) using UEET technologies. All the engines were designed to meet or exceed the two opposing UEET goals of 70% NO<sub>x</sub> reduction relative to the 1996 ICAO LTO NO<sub>x</sub> standard and 15% CO<sub>2</sub> reduction for the subsonic transports and 8% CO<sub>2</sub> reduction for the supersonic business jet relative to the current technology baselines.

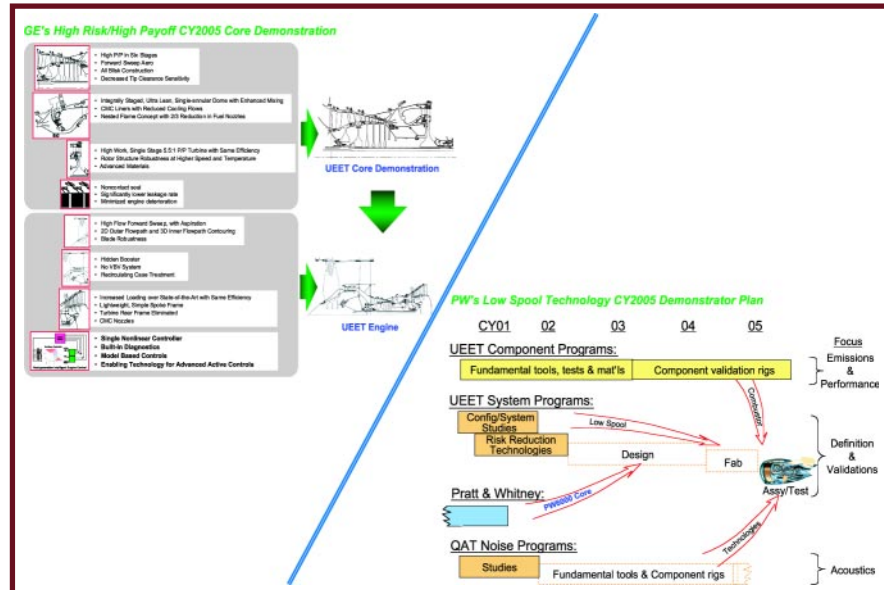
**Validation of Milestone Completion:** The study results will be documented in contractor reports and appropriate publications in fiscal year 2002. The effort was conducted by industry and NASA systems technology experts.

**Next Steps:** The study results and system concepts will be updated and modified as appropriate throughout the UEET Program as individual technology readiness levels are increased. These baselines will be used to assess overall impact of the individual UEET technologies and report overall impact of the program to customers and stakeholders.

## Complete Integrated Component Technology Demonstration (ICTD) Plans for Large Thrust Class Engines

**Point of Contact:**  
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(714-08)

**Actual Date of  
Accomplishment:**  
July 30, 2001



**Project:** Integrated Component Technology Demonstrations, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Reduced Emissions (prime) Revolutionize Aviation/Reduced Noise (secondary).

**Relevant Milestone:** Complete ICTD plan for large thrust class engines. This is a level I Program milestone.

**Milestone Objective:** Complete development of comprehensive plan for NASA/DoD/Industry partnership tests of engine demonstrators incorporating UEET technologies.

**Milestone Minimum Success Criteria:** Complete initial development of plan for collaborative tests of engine demonstrators incorporating UEET technologies.

**Impact of Technology:** The technology demonstrator plan will be used by the UEET management as a strategic planning and advocacy document to determine partnership opportunities to carry selected UEET technologies to a readiness level of 6.

**Shown:** Core Technology Demonstration and Low Spool Technology Demonstration approaches proposed by General Electric and Pratt & Whitney respectively.

**Accomplishment/Relation to Milestone and ETO:** Systems studies were conducted by the engine companies to define innovative propulsion systems and determine individual benefits of advanced technologies. High payoff/high risk technologies were determined by conducting benefits assessments. Plans were formulated to develop these high priority technologies to Technology Readiness Level of 6 as part of integrated system demonstrations. The UEET innovative engine configurations and advanced technologies proposed in these studies contribute toward Goal One: Revolutionize Aviation/Objective 2: Reduce Emissions. Specifically, these propulsion systems were optimized to reduce emissions such as NO<sub>x</sub> that have an impact on local air quality and CO<sub>2</sub> that affect the global climate.

**Validation of Milestone Completion:** The industry studies were performed by General Electric Aircraft Engines and Pratt & Whitney under contract to NASA. The results will be documented in reports to be published in fiscal year 2002.

**Next Steps:** The plan will be updated to reflect potential partnership activities with the DoD through the Integrated High Performance Turbine Engine Technology (IHPTET) and Versatile Affordable Turbine Engine (VAATE) programs.

## Flow Control Concept Selected for Low-Pressure Turbine (LPT)

### Point of Contact:

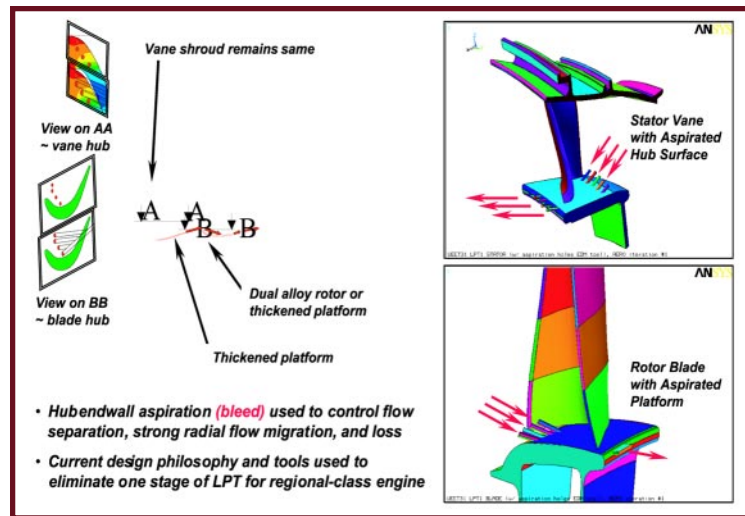
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Research Center  
(714-03-40)

### Technical Lead:

Dr. John J. Adamczyk

### Actual Date of Accomplishment:

September 30, 2001



**Project:** Highly-Loaded Turbomachinery, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Reduced Emissions.

**Relevant Milestone:** Select a candidate turbine flow control concept for ultra-high aerodynamic loading (Milestone No. 8).

**Milestone Objective:** Select a turbine flow control concept that will allow for 50% greater stage loading with <1% net mass flow.

**Milestone Minimum Success Criteria:** Select a turbine flow control concept that will allow for 30% greater stage loading with <1% net mass flow.

**Impact of Technology:** Flow control approaches, once demonstrated in turbine applications, will enable future turbine engine designs with significantly fewer (up to 50%) LP turbine stages and/or higher operating pressure ratios. Resultant propulsion system weight reductions will contribute to reduced fuel burn levels and therefore reduced environmental impact of future aerospace vehicles (i.e. reduced CO<sub>2</sub> emissions).

**Shown:** The graphic above shows a cross section of the redesigned 2-stage Low Pressure Turbine (LPT) incorporating a concept for hub endwall aspiration (bleed) to control flow at the hub surface and allow higher stage loading.

### Accomplishment/Relation to Milestone and ETO:

A 2-stage highly loaded low pressure turbine aerodynamic and mechanical design was completed demonstrating flow control concept in LPT design. The first and second stage of the new LPT has a minimum of 37% increased stage loading compared to the first and second stage of the current 3-stage LPT. Thus the minimum success criteria for this milestone was met. The study was conducted by Honeywell with the baseline being a state-of-the-art regional engine design (and therefore representative of the best technology in the field.) The advanced technology concept developed in this study shows promise of eliminating one stage of an LP turbine for regional class applications. The removal of one of three stages of the LP turbine could have a significant weight reduction impact on future regional engine designs.

**Validation of Milestone Completion:** The results of the study were reviewed by NASA and industry technologists and presented at the UEET Technology Forum held at GRC on September 5-6, 2001. The results of the study will be published in a NASA contractor report in fiscal year 2002.

**Next Steps:** Hardware to evaluate the concept selected for LPT flow control will be fabricated and rig tested. This test which should occur in the fiscal year 2004-2006 time period will mature the technology to a readiness level of 4.

## Fan Flow Control Concept Selected

### Point of Contact:

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(714-03)

### Technical Lead:

Brian Fite  
NASA Glenn  
Research Center

**Actual Date of  
Accomplishment:**  
March 30, 2001

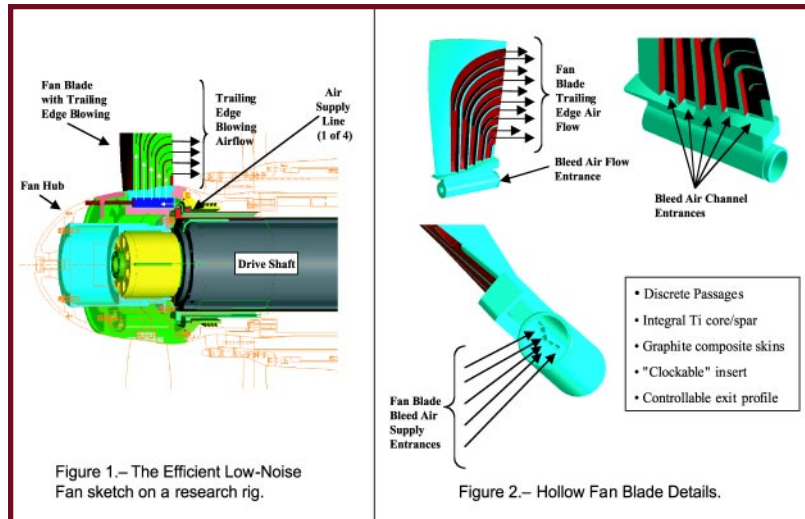


Figure 1.— The Efficient Low-Noise Fan sketch on a research rig.

Figure 2.— Hollow Fan Blade Details.

**Project:** Highly Loaded Turbomachinery, Ultra-Efficient Engine Technology Program

**Enterprise Objective(s) Supported:** Revolutionize Aviation/Reduced Emissions (prime), Revolutionize Aviation/Reduced Noise (secondary)

**Relevant Milestone:** Flow Control Concept Selected-Fan, March 31, 2001. This is a level I Program milestone.

**Milestone Objective:** Eliminate trailing edge fan rotor wake velocity deficit (100% wake filling) with < 1% mass flow and no increase in noise.

**Milestone Minimum Success Criteria:** Achieve partial span filling of fan rotor wake with < 1% mass flow and no increase in noise.

**Impact of Technology:** The flow control concept for the fan (blown trailing edge) was collaboratively selected by the UEET and QAT Programs to ensure that fan aero performance and weight, and hence fuel burn (i.e., emissions) are not adversely impacted by low-noise technologies. This concept, once demonstrated in a fan rotor application, will enable future turbine engine designs with reduced overall environmental impact (i.e., reduced noise and emissions).

**Shown:** Figure 1 shows the Efficient Low-Noise Fan sketch on a research rig. The fan blades are hollow so that bleed can go through the fan blade, exit the trailing edge, and fill the wake created by the fan blade. Figure 2 shows more details of the hollow fan blade.

**Accomplishment/Relation to Milestone and ETO:** New concepts dealing with fan section designs were submitted by both NASA and industry to help meet UEET (reduced CO<sub>2</sub>) and QAT (reduced noise) goals. The number one concept selected for testing was "Fan Blade

Trailing Edge Blowing," based on Computational Fluid Dynamics (CFD) simulation. This concept will meet both UEET and QAT Program goals. The impact of the "Fan Blade Trailing Edge Blowing" concept is to reduce the strength of the wakes downstream of the fan blades by filling in the wakes with the Fan Blade Trailing Edge bleed flow, thereby allowing rotor/stator spacing in the fan stage to be decreased significantly. The accomplishment meets the minimum success criteria of achieving partial span filling of fan rotor wake with < 1% mass flow with no increase in noise. Potential benefits may include an efficiency gain due to reduced fan rotor/stator spacing as the result of better wake mixing, weight savings from overall length reduction allowed by closer fan/stator spacing, potential additional weight savings (blade lighter, disk lighter, and containment structure lighter), and significant potential noise reduction.

**Validation of Milestone Completion:** The CFD simulation studies done by both NASA and industry personnel were accomplished with simulation tools used and accepted by the aerospace industry. The results of the studies were evaluated by NASA and industry experts prior to the selection being made. The results of the studies are documented in technical presentations as well as NASA and contractor publications.

**Next Steps:** Hardware to evaluate the concept selected for fan flow control will be fabricated and tested in the NASA Glenn Research Center's 9x15 Low Speed Wind Tunnel (LSWT). This test scheduled for fiscal year 2004 will be done in partnership with the QAT Program. The test will evaluate both the aerodynamic and acoustic performance of the concept and mature the technology to a readiness level of 3.



# ***Future Plans***



## Future Plans

The accomplishments the UEET Program achieved during the first two years of the program have provided a solid foundation for the future.

Specifically, the outstanding results gathered to date from the flame tube experiments for Ultra Low NO<sub>x</sub> give renewed confidence that the sector tests to be conducted in fiscal years 2002 and 2003 will determine realistic approaches for maintaining low levels of pollutants while retaining high degrees of combustor performance and operability which are required if the technologies are to be utilized in future low emission engines. The sector tests will be followed by full annular rig tests of the most promising approaches for both large and regional engine applications. These TRL5 tests will provide confidence to both NASA and the corporate partners that the combustor configurations are ready for TRL6 engine testbed demonstrations which could be done by NASA and industry in a cost sharing partnership fashion. Currently these engine demonstrations are not in the baseline UEET plan displayed in the Appendix.

A new turbine test facility, the Dual Spool Turbine Facility (DSTF) will be brought online at NASA Glenn in fiscal year 2005 with all funding provided by the UEET Program. This facility will give NASA and its partners in the effort—General Electric, Pratt & Whitney, Air Force Wright Laboratories, and Ohio State University—a unique test facility to understand the fluid physics of closely coupled, highly loaded turbine designs. Future commercial, military, and access to space turbine engine systems require fewer stages to reduce the system weight while maintaining high levels of performance and operability. The DSTF will allow for orderly, disciplined research to be conducted to significantly improve the fluid physics understanding and therefore make a significant contribution to validating the design tools needed by our corporate partners if significant advances in future turbine engine designs are to be accomplished.

In addition, the turbomachinery project will validate through rig testing (TRL4) technologies which will enable future industrial designs of compressors with aerodynamic loading far in excess of today's state-of-the-art.

The materials and structures efforts in the out years will emphasize the development of ceramic matrix composite materials (CMC's) for both combustor liner and turbine vane applications. In fiscal year 2003 an engine demonstration (TRL6) will be conducted for the 2200 degree F CMC material developed in the High Speed Research (HSR) Program. This TRL6 test done in partnership with General Electric will effectively transition this first generation CMC to industry. The ongoing UEET efforts will focus on upgrades to the CMC material system, which will enable 2400-degree temperature capability. For both the 2400-degree F combustor liner and the turbine vane applications, the materials technologies will be validated through appropriate rig (TRL4) tests in the UEET Program.

The Intelligent Propulsion Controls (IPC) project will be formally initiated in fiscal year 2002. The IPC project will focus on two technology areas: turbine engine clearance management and wireless technologies. The clearance controls efforts will validate both slow and fast response approaches for maintaining high levels of engine performance throughout the life of the engines. The wireless technologies will provide validation of enabling technologies required for future advanced engine designs which feature large arrays of sensors to continuously monitor engine conditions and adjust operating parameters without human intervention so as to maximize performance and minimize environmental impact across the mission profile. The technology products delivered by the IPC project will provide a first, critically important step towards realizing a future vision of truly intelligent, autonomous engines. Such engine designs will provide truly revolutionary improvements over the current state-of-the-art.

The Propulsion Airframe Integration (PAI) project will validate enabling technologies required for future aerospace vehicles, which have highly integrated propulsion systems. The active flow and shape control technologies will enable industry to design future propulsion systems (including inlets) which are short, compact, and highly three dimensional in nature and exhibit significantly increased levels of performance and operability relative to today's state-of-the-art.

In all cases for the technologies being developed in the UEET Program, the products delivered will provide the basis for NASA partnering with DoD and/or industry to bring them to a readiness state (TRL6) such that they can be incorporated in future engine designs. These technology demonstrations are not currently contained within the baseline program but appropriate risk sharing partnerships will continue to be sought and program funds will be redirected as appropriate.

In addition the UEET Program will continue to develop partnerships wherever appropriate with other NASA and DoD programs. These partnerships provide two benefits—more rapid technology dissemination and reliance between partners, which will result in increased return on taxpayer investment. Finally the UEET Program will continue to look beyond the conventional aerospace partners for technology transfer and commercialization. Together with the NASA Commercial Technology Offices and the National Technology Transfer Center (NTTC), UEET will explore non-aerospace partnership opportunities.

We believe the future for the UEET Program is very positive. Through systems studies, we have identified a portfolio of high payoff technologies for future turbine engines. These technologies are applicable

to future commercial (subsonic and supersonic), military, and access to space applications. In general the UEET Program will bring these technologies to a maturity level of TRL3–5. Our partnership with industry, academia, and DoD is strong and will contribute greatly to the overall success of the program. We will continue to execute our aggressive education/outreach plan, which has been well received by customers and stakeholders. The education portion of this effort will continue the development of products, which can be used by students, and teachers in K-12 to explain the basic principles of aviation and encourage students to consider careers in aerospace related fields.

The UEET studies we have conducted of potential future engine concepts shows the gas turbine engine is anything but a mature approach for powering future aerospace vehicles with little improvement possible over today's state-of-the-art. Quite the contrary, we see potential for significant improvements in performance while continuing to reduce both emissions and noise. The UEET Program will make a significant contribution to realizing these future engine concepts. The enabling technologies being developed by the UEET Program will contribute to the future economic and military strength of our country.



National Aeronautics and  
Space Administration

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